Higgs mechanism as a magnetic picture of dynamical symmetry breaking (super-topcolor model)

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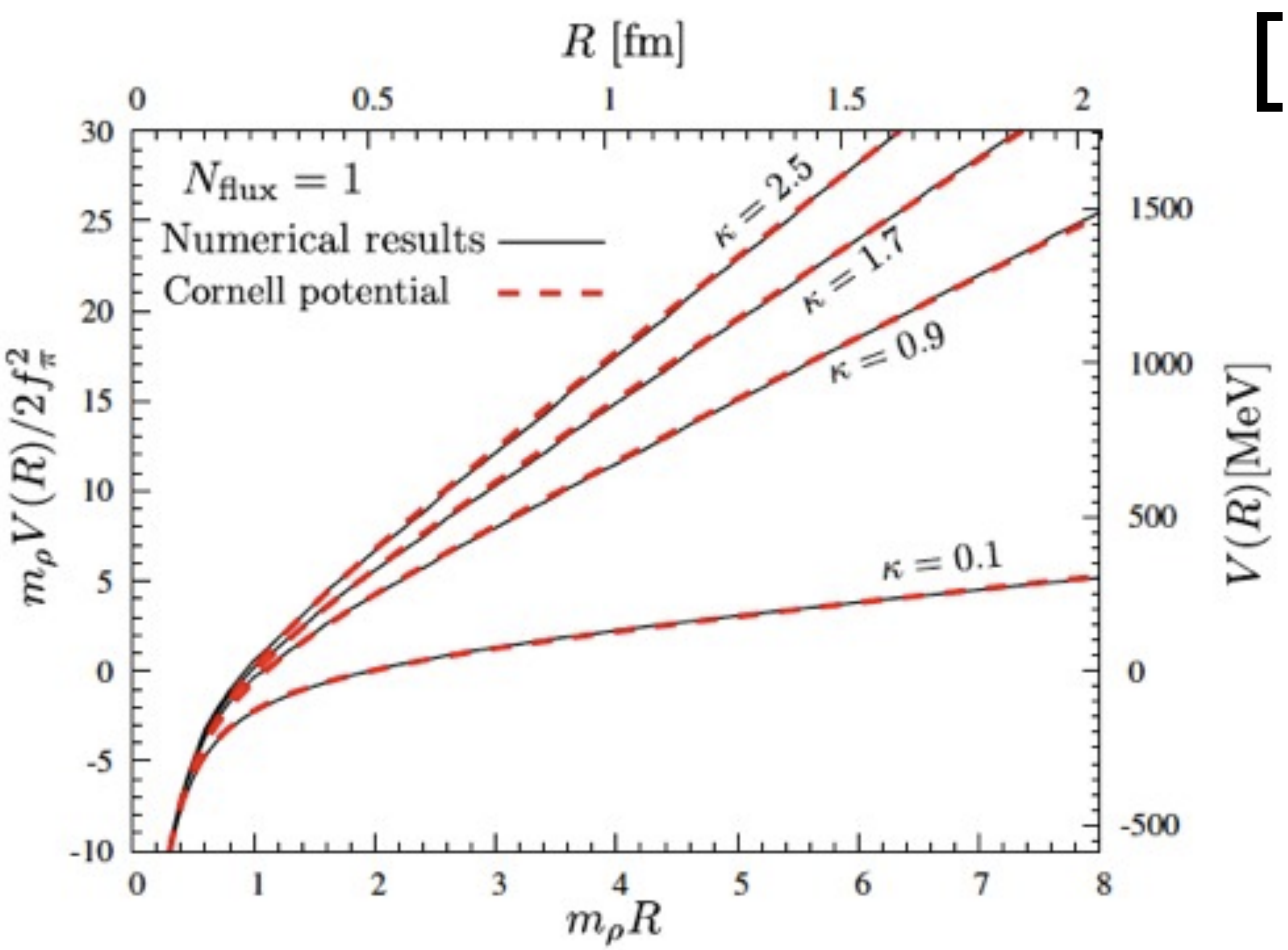
ρ meson as magnetic gauge boson

In QCD, $\rho/\omega/f_0/a_0$ system can be interpreted as a magnetic picture which is a Higgsed gauge theory.

[RK, Nakamura, Yokoi '12]



QCD potential (confinement) is explained by the classical string configuration of hadrons.

Maybe electroweak physics is similar

Higgs = composite field

= Magnetic degree of freedom?

But we know that theories too similar to QCD will not be good, since that's just the QCD-like technicolor paradigm.

Supersymmetry

SUSY gauge theory may be an interesting possibility.

light scalar can survive naturally.

$\longrightarrow$ Good for precision tests.

boson-boson composite has smaller dimension compared to fermion-fermion ones

$\longrightarrow$ Good for fermion mass vs FCNC problem

Super-Topcolor model

[RK, Fukushima, Yamaguchi ’10]

(Similar models [Evans, Golloway, Luty, Tacchi ’10]
[Craig, Stolarski, Thaler ’11] [Csaki, Shirman, Terning ’11]
[Csaki, Randall, Terning ’12])

Just a supersymmetric extension of the topcolor model [Hill ’91]

$SU(3)_{TC} x SU(3)_{C'} x SU(2)_L x U(1)_Y$

t^c, b^c

q_L

$$Q = \begin{pmatrix} (1,2)_{1/6} \\ \hline (\bar{3},1)_0 \end{pmatrix}, \quad \bar{Q} = \begin{pmatrix} (1,1)_{-2/3} \\ (1,1)_{1/3} \\ \hline (3,1)_0 \end{pmatrix}$$

Φ

3 under $SU(3)_{TC}$

$\overline{3}$ under $SU(3)_{TC}$

both are chiral superfields

It is an SUSY QCD (SU(3)) with 5 flavors. Properties are well-known.

We also add soft SUSY breaking terms and a mass term for Φ

In fact, SU(3) 5 flavor theory is in the conformal window:

$$3N_C/2 < N_f < 3N_C$$

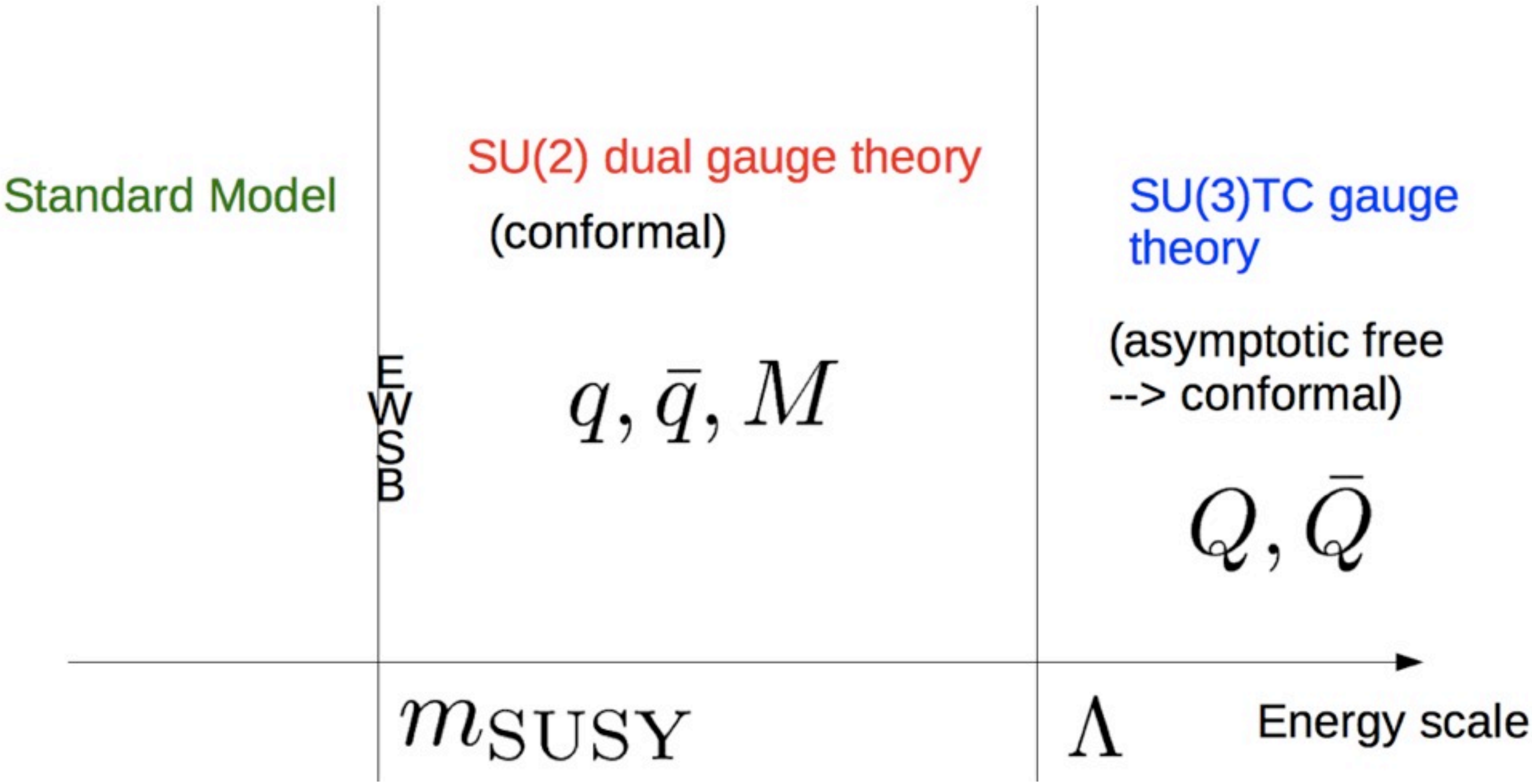
$$\longrightarrow \quad 4.5 < N_f < 9 \quad \text{for} \quad N_c = 3$$

N_f=5 is at the most strongly coupled point in the conformal window.

This means the Seiberg dual theory is at the most weakly coupled point in the conformal window.

$\longrightarrow$ One can do perturbative calculation (expansion in terms of $1/N_f$)

Weakly coupled descriptions



The dual theory (for $\Lambda >> m_{SUSY}$, the use of duality is justified.)

The dual theory is $SU(N_f-N_c)$ with N_f flavor. $\longrightarrow$ SU(2) 5 flavor

meson:
(SU(2) singlet)

Higgs! Top/bottom!

$$M = \left(\begin{array}{cc|c} H_d & H_u & q_3 = \begin{pmatrix} t \\ b \end{pmatrix} \\ \hline t^c & b^c & X \end{array} \right)$$

Color adjoint
+ singlet

(looks like the MSSM)

dual quarks:
(SU(2) doublet)

$$q = \left(\begin{array}{c} (1,2)_0 \\ \hline (3,1)_{1/6} \end{array} \right), \quad \bar{q} = \left(\begin{array}{c} (1,1)_{1/2} \\ (1,1)_{-1/2} \\ \hline (\bar{3},1)_{-1/6} \end{array} \right)$$

(looks like a minimal technicolor)

Superpotential: $W = hqM\bar{q}$

h is a coupling constant.

One can see that the Higgs and top/bottom are the effective d.o.f.

Soft SUSY breaking terms in CFT

There are interesting RG behaviors of soft SUSY breaking terms in CFT.

[Arkani-Hamed, Rattazzi '98][Karch, Kobayashi, Kubo, Zoupanos '98]
[Luty, Rattazzi '99][Abel, Buican, Komargodski '11]

Essentially, all the soft terms vanish at the fixed point except for the D-terms associated with U(1) global symmetries.

$$\tilde{m}^2_{Q_i} = q_i^a D^a$$

This leads sum rules among soft scalar masses for mesons.

$$\boxed{\begin{gathered} \tilde{m}^2_{X_1} = \tilde{m}^2_{X_{\mathrm{adj.}}}, \\ \tilde{m}^2_{H_d} - \tilde{m}^2_{H_u} = \tilde{m}^2_{t^c} - \tilde{m}^2_{b^c}, \\ \tilde{m}^2_{H_d} + \tilde{m}^2_{X_1} = \tilde{m}^2_{q_3} + \tilde{m}^2_{t^c}, \\ m^2_{H_u} + m^2_{H_d} + 3m^2_{X_1} = 0. \end{gathered}}$$

No A-terms, no gaugino masses.

Electroweak Symmetry Breaking

We are interested in a vacuum with $\langle M \rangle \neq 0$

$\longrightarrow$ By superpotential, the dual quarks are massive.

$\longrightarrow$ Integrate out dual quarks

We get an effective (non-perturbative) superpotential:

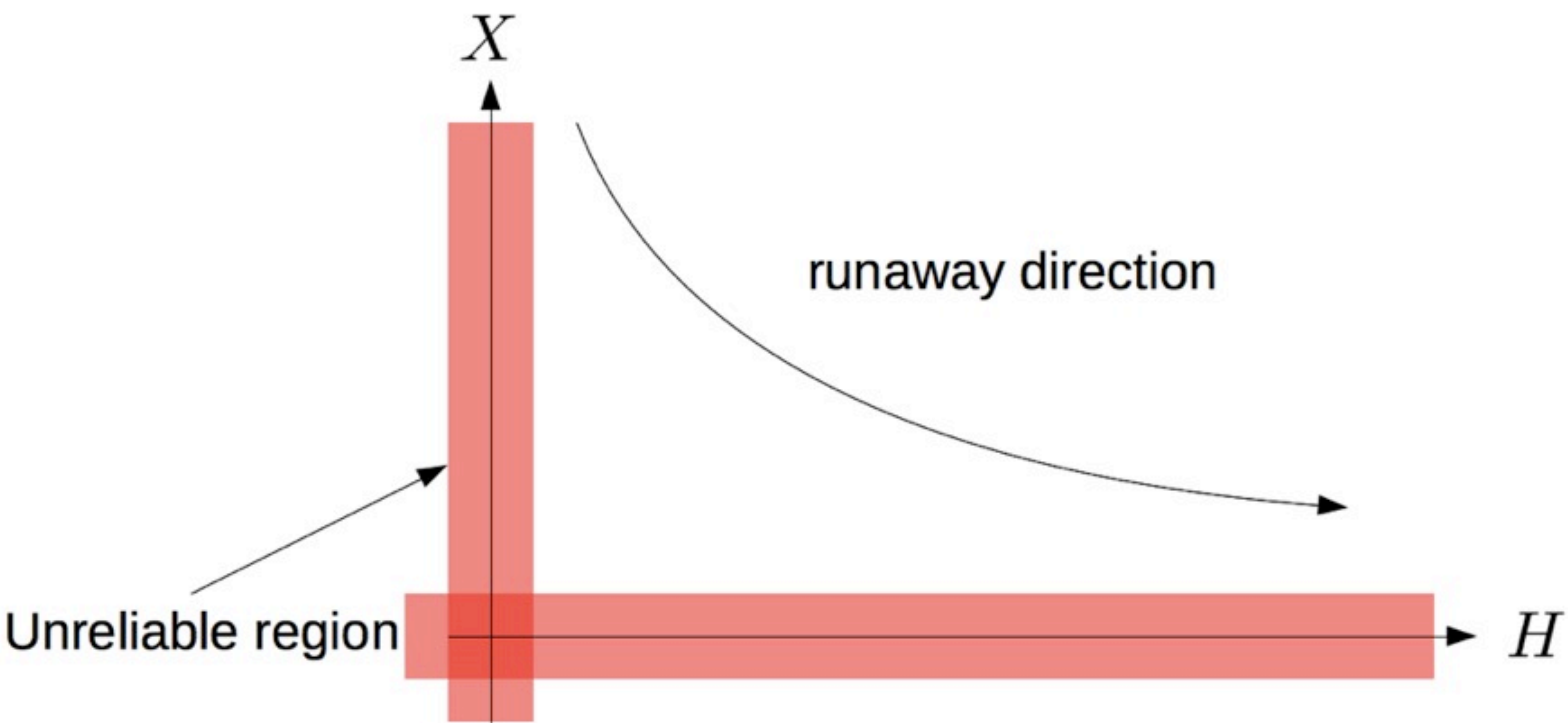
$$W_{\rm eff} = \kappa N \left(\frac{h^{N_f} \det M}{\Lambda_*^{N_f - 3N}} \right)^{1/N} + \mu_X^2 \, {\rm Tr} X$$

where $\kappa \sim \frac{1}{16\pi^2} e^{-8\pi^2/g_* N} \sim \frac{1}{16\pi^2} e^{-N_f/7}$

The use of effective superpotential is valid when

$$h\langle M\rangle \gg m_{\rm SUSY} \, .$$

Now, the effective superpotential gives a runaway potential:



SUSY breaking terms

From the sum rules, the signs of the soft mass^2 are restricted.

By requiring that the stop/sbottom are not tachyonic, we get

$$\tilde{m}_H^2 > 0, \quad \tilde{m}_{X_1}^2 < 0.$$

→ Pulls H to origin, X to infinity

→ Runaway potential is stabilized!

VEVs?

The minimization of the potential gives

$$m_{\mathrm{SUSY}} \sim \kappa h^3 v$$

where $\quad v \sim \langle M \rangle$

Since the theory is (semi) weakly coupled,

$\kappa h^3 \sim 1 \quad \longrightarrow \quad$ Analysis is barely reliable.

The Higgs boson mass

We saw that the Higgs potential is "stabilized" by SUSY breaking.

(rather than "destabilized" by SUSY breaking and "stabilized" by the gauge interaction.)

→ Higgs mass is unrelated to the Z boson mass.

→ No tension from LEP-II bound on the Higgs boson mass.

or LHC

Top quark mass

Let's go back to a large N theory so that one can do perturbative calculation.

The fermion masses are generated through the non-perturbative superptential.

$$m_F^{ij,kl} = \frac{\partial^2 W_{\rm eff}}{\partial M_{ij} \partial M_{kl}} = \kappa h^3 (\det M)^{3/N_f} \left(\frac{1}{N} (M^{-1})_{ji} (M^{-1})_{lk} - (M^{-1})_{li} (M^{-1})_{jk} \right)$$

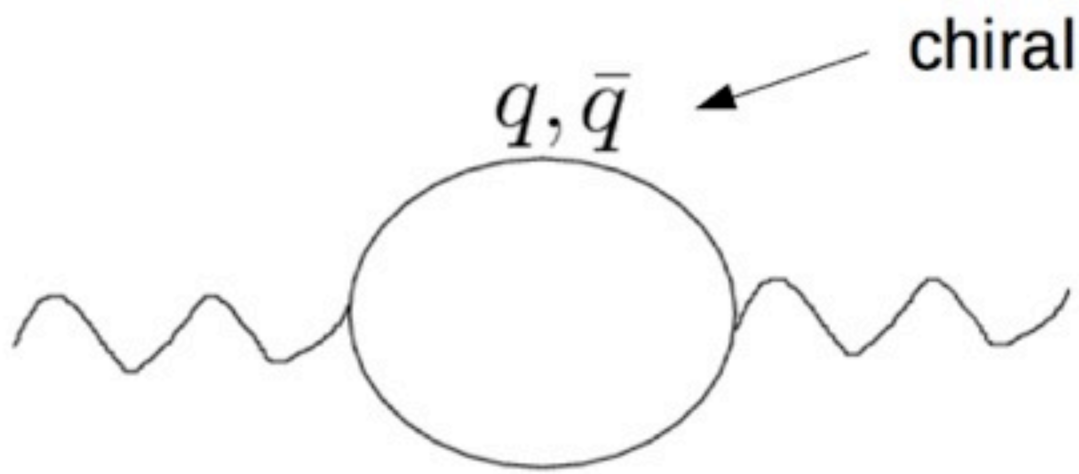
The top/bottom, Higgsinos obtain masses at the vacuum.

$$m_t \sim \kappa h^3 v \sim m_{\rm SUSY}$$

This is a desired relation.

S,T parameters?

In the large N theory, new contributions other than the SM particles are the loop of dual (s)quarks.



At leading order in 1/N (again 3N-N$_f$ fixed to be 1)

$$\Delta S = \frac{N}{6\pi}.$$

$$\Delta T = 0.15 \left(\frac{5}{N_f}\right) \quad (\tan\beta = 1.1),$$

$$\Delta T = 0.57 \left(\frac{5}{N_f}\right) \quad (\tan\beta = 1.2).$$

Looks OK for N=2 and tanb~1 together with a not-so-heavy Higgs boson.

LHC?

This model has a rich structure.

It includes MSSM + technicolor.

LHC will find both SUSY and technicolor.

Also, there is X which is color adjoint. It can be resonantly produced and decays into tt or bb.

Summary

SUSY + topcolor looks like a good combination.

(Although we still need to consider bottom mass etc.)

Dynamical EWSB + Dynamcial top mass generation can be seen at least at a large Nf extension of the theory.

LHC will find many new particles.